Toward Routine Autonomous Measurement and Interpretation of Optical Variability In Coastal Waters

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LONG-TERM GOALS

Optical measurements can be used for describing oceanographic processes and for developing predictive models. However, a great deal of time and expertise is required for quality control, data management, and interpretation of results. The full potential of optical observation technology for oceanography will be realized only when appropriate measurements can be made routinely, with automatic generation of robust interpretations. Toward that end, our long-term goal is to broaden the utility of radiometric measurements (upwelling radiance and downwelling irradiance) so that turnkey systems can be developed for the generation of derived data, suitable for use by non-experts.

SCIENTIFIC OBJECTIVES

This program of research is aimed at supporting the efforts of primary researchers to interpret water-leaving radiance as measured by radiometer buoys in coastal waters. Complementary measurements with profiling and airborne radiometers are also addressed. Efforts are directed toward: (1) characterizing instrument behavior in the field to define information potential and limitations of the measurements; (2) developing statistical methods for averaging data and rejecting spurious observations; (3) refining algorithms relating optical measurements to properties of surface waters; and (4) supporting efforts to obtain novel information from radiometer buoys (e.g., ultraviolet attenuation and influence of bubbles).

APPROACH

This work is closely coordinated with the NSERC/Satlantic Industrial Research Chair in Environmental Technology, a partnership between John Cullen (the Chair), Dalhousie University and Satlantic. The Research Chair facilitates collaborative research. This ONR project provides funding for additional technical support from Satlantic which complements Dalhousie-based efforts. Research is conducted with: Dr. William Miller (Dalhousie), who is studying the optical properties of coastal waters in relation to photochemical transformations of dissolved organic matter; researchers from NOAA (including P.J. Stabeno and J. Napp), in projects to characterize bio-optical variability in the Bering Sea; and a team

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from the Maurice Lamontagne Institute, Fisheries and Oceans Canada (P. Larouche: Chief, Coastal Processes), looking at optical variability in estuarine and coastal waters of Canada. The approach is to pursue basic questions in bio-optics during collaborative research cruises and to use this ONR-sponsored effort to improve technologies for measurement, data analysis and interpretation. Integrated with this is are the university-based research programs of Lewis and Cullen, directed toward improved interpretations of near-surface optical measurements.

WORK COMPLETED

Instrumentation and procedures for data reduction. A 14-channel, UV-visible reflectance radiometer buoy was deployed this year during cruises off the east coast of the US, and in the estuary and Gulf of St. Lawrence. A 13-channel, UV-visible profiling radiometer was used to estimate diffuse attenuation coefficients during the deployments. Improved procedures for dark-current correction and for estimation of near-surface diffuse attenuation coefficients were developed and tested on data from a variety of water types (Sildam et al. 1998). Procedures for atmospheric and sun-glint corrections of measurements from airborne radiometers were also improved (Lazin et al. 1998). Data from a radiometer buoy with k-chain (string of irradiance sensors to measure diffuse attenuation coefficients), were analyzed (Lewis 1997, Ciotti et al. 1998), and the system was deployed again in 1998. The first data from a hyperspectral radiometer buoy were acquired and subjected to preliminary analysis (Weidemann et al, 1998).

Analysis and interpretation of data. Observations from radiometer buoys, drifters and airborne radiometers were used to describe interpretable features in the relationship between sun-induced chlorophyll fluorescence and irradiance, and measurements on discrete samples were used to confirm physiological interpretations of sun-induced fluorescence patterns (Cullen et al. 1998). Data from our optical instruments, and our interpretations of optical data were used in several collaborative presentations and publications (Foley et al., 1997; Landry et al., 1997; Korotaev et al., 1998). The utility of optical observations for detecting and assessing algal blooms was discussed and results were presented in a paper for a special issue of Limnology and Oceanography (Cullen et al. 1997) and several invited presentations.

Operational advances. Improvement in instrument design, including the addition of UV wavelengths, as well as the development of better procedures for preliminary data analysis, have moved us closer to routine acquisition of derived products from measurements with radiometer buoys, airborne radiometers and profilers. A light source for field calibrations was developed (McLean et al. 1998). Methods for assessing sun-induced fluorescence (with and without a channel in the far red; Cullen et al. 1998) will be useful for exploiting data from airborne sensors. An approach for quantifying the spectral effects of clouds on irradiance (Bartlett et al. 1998) increases the utility of broad-band or single wave-band measurements of solar irradiance, providing a means to estimate changes in spectral quality.

Semi-analytical model. Results from previous studies of upwelling radiance and downwelling irradiance in coastal waters were analyzed further and presented in an improved theoretical context. One result is a Semi-Analytical Model of Ocean Color and Attenuation as a Function of Trophic Status (SAMOCAFOTS; Ciotti et al. 1998), which parameterizes the relationship between blue:green upwelling radiance ratios (ocean color) and diffuse attenuation at 490 nm (e.g. Austin and Petzold 1981) as a function of the optical properties of phytoplankton and the concentration of colored dissolved organic matter (CDOM) and detritus, all of which are expressed as functions of chlorophyll concentration (*C*). The model predicts spectral absorption, scatter and backscatter as functions of *C*, consistent with lab studies and well recognized empirical relationships. The parametrization allows the development of

regional algorithms and evaluation of deviations from typical Austin-Petzold type relationships between ocean color and diffuse attenuation. SAMOCAFOTS also generates other bio-optical relationships (e.g., pigment algorithms) that can subjected to sensitivity analysis to explore the influences of phytoplankton community structure, inorganic particles, or CDOM. Further analysis (Ciotti et al. unpublished) shows that a large proportion of the variability in spectral absorption of phytoplankton communities can be accounted for with a simple measure of dominant cell size, and a single spectral trend describing size-correlated changes in absorption spectra. Recent work on the effects of bubbles on scattering (Zhang et al 1998 a, b) can be incorporated into optical models yielding useful predictions and directions for research. For example, bubbles will have a strong effect on relationships between reflectance and diffuse attenuation, much different that that of phytoplankton.

Ultraviolet radiation. The move to UV wavelengths in our research program (Miller) opened new avenues for research. Complementary studies on the biological effects of UV culminated in a full-spectral model of UV effects as influenced by ozone depletion and vertical mixing (Neale et al. 1998 a, b). The model has now been improved and adapted (and procedures for calculating action spectra have been streamlined) , so it can be used for characterizing effects of mixing on a broad variety of biological and photochemical processes. As a result, new collaborations have been established. Meantime, work continues on the procedure for estimating diffuse attenuation of UV, photochemical fluxes and biological effects of UV, based on measurements of upwelling radiance in the visible.

IMPACT/APPLICATIONS

The research associated with this project, along with rapid advances by other workers, is moving us steadily toward achieving the stated goal of developing turnkey systems for measuring upwelling radiance and downwelling irradiance in surface waters and delivering derived data on water clarity and variability of important constituents of surface waters. Progress to date indicates that optical instruments will figure prominently in systems for routine environmental assessment and prediction in coastal waters as well as for rapid deployment and assessment in critical situations. Discoveries of provocative patterns in sun-induced fluorescence suggest promising lines of research, particularly with respect to hyperspectral remote sensing. Research on ultraviolet radiation in surface waters has revealed great potential for new applications in remote sensing and autonomous observation systems. The link between ocean optics and UV research (photochemistry and photobiology) will continue to strengthen in the next few years.

TRANSITIONS

Interest in this work is reflected in frequent inquiries from colleagues, requests to deliver talks (including the ONR HyCODE workshop), invitations to participate in workshops, and appointment of J. Cullen as chair of an international workshop to develop plans for a program on harmful algal blooms. The proposed program will have direct links to the Global Ocean Observing System, with a strong potential for further development of bio-optical studies in coastal waters.

RELATED PROJECTS

1) NSERC/Satlantic Industrial Research Chair: this partnership is the central source of support for instrumentation, field work, lab studies, and university salaries. Funding for complementary projects, such as this ONR program, are highly leveraged by the research partnership.

2) W.L. Miller, Dalhousie (ONR): photochemical processes and optical properties of surface waters. We participate in the cruises, share data, and collaborate on analysis. Our modelling efforts are directly relevant to their objectives. Miller focuses on photochemical processes, we emphasize optical properties.

3) NOAA-funded work in the Bering Sea (J. Cullen and R. Davis): optical observations from ships, moorings, drifters and aircraft are used to describe bio-optical variability in the Bering Sea as related to physical forcing (P.J. Stabeno, NOAA) in the context of fisheries oceanography (J. Napp, NOAA). Funding from ONR allows us to append research on UV and photochemistry, and fluorescence.

4) Research on migrating phytoplankton (Richardson et al. 1998) harmful algal blooms (e.g., Cullen and MacIntyre 1998), partially funded by NSERC and the ECOHAB program, provides information on physiological and optical characteristics of phytoplankton (including fluorescence) that is directly relevant to bio-optical characterization of coastal waters.

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